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# Biogas from palm oil mill effluent (POME): Opportunities and challenges from Malaysia's perspective

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ABSTRACT

The generation of palm oil mill effluent (POME) alongside with the production of crude palm oil has created environmental issue for the palm oil mill industry in Malaysia due to its polluting characteristics. POME with its high organic content is a source with great potential for biogas production. However, POME is commonly treated using open ponding system just to comply with government regulation without capturing biogas released from the process. Biogas generated from anaerobic digestion of POME can replace palm kernel shell and mesocarp fiber which has higher economic value as boiler fuel; upgraded to be used in gas engine for power generation. It is estimated that net profit of RM 3.8 million per year can be obtained in a palm oil mill with processing capacity of 60 tonnes/hr from electricity generation using biogas produced from POME treatment. This review paper will elaborate on the potential of POME as a source of renewable energy and the challenges faced by the palm oil mills in Malaysia which deters the development of biogas plants in the mill.



**Contents**



## 1. Introduction

The palm oil industry has grown tremendously in the recent years and accounted for the largest percentage of oil and fats production in the world in 2011. Based on Fig. 1, production of palm oil superseded soybean oil from just 13% in 1990 to 28% of total oil and fats production in 2011. This is because oil palm has higher annual oil yield per hectare compared to other oilseeds crops including soybean [1] and palm oil has a relatively lower price as compared to the major alternative vegetable oils [2]. With the higher global demand of palm oil, Malaysia has developed its palm oil industry to become one of the largest palm oil exporters and producers in the world. Malaysia's palm oil export accounted for 46% of world exports and 37% of world palm oil production in

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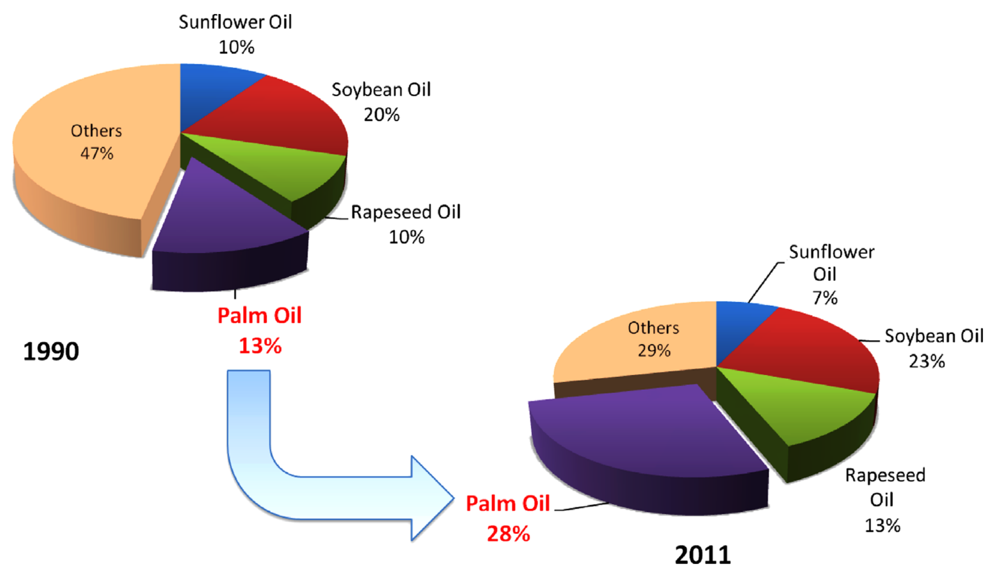


**Fig. 1.** World oil and fat production in 1990 and 2011[1,3].

**Table 1**
Characteristics of raw POME.

| Parameter | Unit | Range | References |
|---|---|---|---|
| pH | – | 4–5 | [62,63] |
| Biological oxygen demand (BOD) | mg/L | 25,000–65,714 | [11,64] |
| Chemical oxygen demand (COD) | mg/L | 44,300–102,696 | [63,64] |
| Total solids (TS) | mg/L | 40,500–72,058 | [9,64] |
| Suspended solids (SS) | mg/L | 18,000–46,011 | [9,64] |
| Volatile solids (VS) | mg/L | 34,000–49,300 | [11,65] |
| Oil and grease (O and G) | mg/L | 4000–9341 | [9,64] |
| Ammoniacal nitrogen ($NH_3$–N) | mg/L | 35–103 | [11,64] |
| Total nitrogen (TN) | mg/L | 750–770 | [11,16] |

2011 [3]. Although the expansion of palm oil industry has boosted the national economy, it also concurrently generated abundant of by-products such as palm oil mill effluent (POME), empty fruit bunch (EFB), palm kernel shell (PKS) and mesocarp fiber in palm oil mills during the processing of palm oil from fresh fruit bunch (FFB) [4,5]. Out of these by-products, POME still remained relatively untapped and will be a threat to the environment if directly discharged to the watercourse [6].

POME is the liquid waste generated from the oil extraction process from FFB in palm oil mills [7]. Typical characteristics of POME are shown in Table 1. This effluent is a thick brownish liquid with high biochemical oxygen demand (BOD) and chemical oxygen demand (COD) [8]. Furthermore, its high solids concentration and acidity causes it to be unsuitable for direct discharge to watercourses. For each tonne of crude palm oil (CPO) produced, it is estimated that 5–7.5 tonnes of water is used and more than 50% of water ends up as POME [9]. This implies that about 2.5–3.75 tonnes of POME will be generated per tonne of CPO production. This huge quantity of POME will pollute the watercourses nearby the palm oil mills without proper waste management implemented in palm oil mills [10]. This problem has become more apparent as the number of palm oil mills in Malaysia continued to increase rapidly from 334 mills in 1999 to 426 mills in 2011 as shown in Fig. 2 [11,12].

In order to control the industrial pollution in the country, regulatory control over discharges from palm oil mills is instituted through Environmental Quality (Prescribed Premises) (Crude Palm Oil) Regulations, 1977 promulgated under the Environmental Quality Act, 1974 and enforced by the Department of Environmental (DOE). The palm oil mills are required to adhere to prescribed regulations, which includes laws governing the discharge of mill effluent into water courses and land [9]. On top of that, the requirement of BOD level of industrial effluent to be discharged to watercourse has been tightened recently by DOE where the prevailing national regulation of 100 mg/L BOD has now been reduced to 20 mg/L for mills in certain environmentally sensitive areas especially in Sabah and Sarawak [13]. Therefore, a reliable and effective treatment process has to be adopted by palm oil mill in order to achieve this stringent standard requirement on effluent discharge consistently.

However, the high organic contents in POME on the other hand have crafted POME to be a good source to generate methane gas via anaerobic digestion. Moreover, POME contains biodegradable constituents with a BOD/COD ratio of 0.5 and this implies that POME can be treated easily using biological means [14]. The most conventional method employed for POME treatment in Malaysia is ponding system whereby more than 85% of the mills have adopted this method due to low operating cost [15]. This system comprises of de-oiling tank, acidification ponds, anaerobic ponds and facultative or aerobic ponds and the number of ponds will be dependent on the capacity of the palm oil mill [6].

Although ponding system is widely used throughout the country, this treatment method is not encouraged due to lacking of operational control and long retention time for degradation [16,17]. Moreover, the biogas produced during the anaerobic decomposition of POME is not recovered for utilization but was allowed to dissipate into the atmosphere. Yacob [18] reported that an average of 54.4% and 1.5 L/min/$m^2$ of $CH_4$ composition and biogas flow rate, respectively, was emitted from anaerobic pond under normal operation condition. In fact, this POME derived biogas which contains mostly methane could be used as an additional source of energy in palm oil mill. In ponding system, this valuable energy source is not only being wasted but also causing detrimental effect to environment due to the high potential of methane gas to cause global warming (with a global warming potential of 25 as compared to $CO_2$) [19].

POME could become one of the promising sources for renewable energy in Malaysia if the abundant of POME (rich in organic matters) generated in Malaysia are being treated in a more efficient closed anaerobic digester system to produce and capture the valuable methane gas (biofuel). At the moment, most research works were aimed to improve methane production. However,

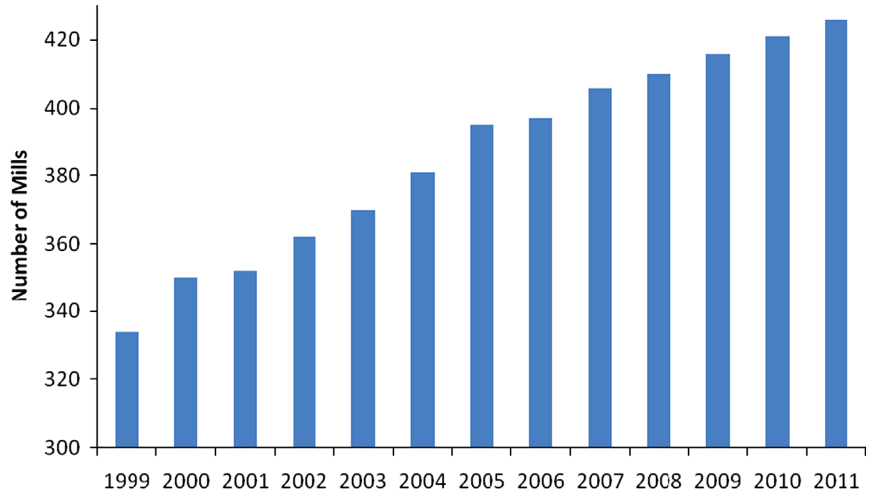


**Fig. 2.** Number of operating palm oil mills in Malaysia from 1999 to 2011 [11,12].

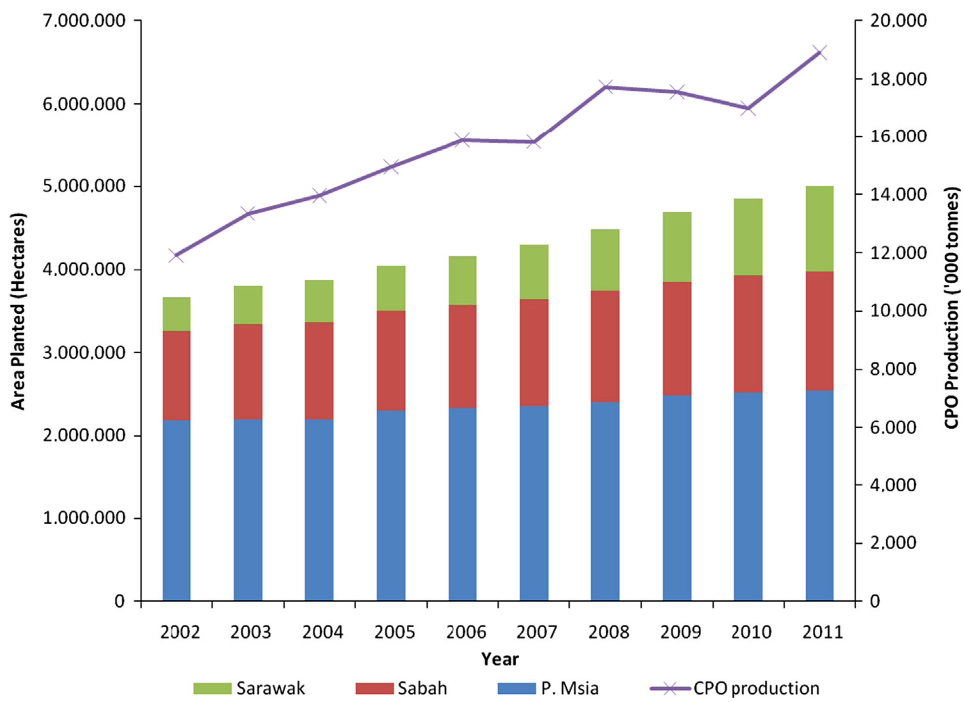


**Fig. 3.** Oil palm plantation area and crude palm oil (CPO) production in Malaysia [58,59].

there is no proper evaluation done on the potential of methane recovery from POME treatment, which will potentially attract the palm oil mills to invest on biogas plants in palm oil mills for POME treatment. Therefore, this paper aims to review the potential of POME as source for methane production and benefits of biogas recovery from POME to the palm oil mills. The current challenges and future perspective of the methane production from POME in Malaysia are also discussed in this paper.

## 2. Potential of biogas production from POME

The concern on the depletion of fossil fuel has led to an increase in research activities on the development of renewable energy such as biogas production from waste for sustainable power generation. POME being a waste with high organic carbon content has became a promising source for biogas production and to potentially boost up the renewable energy sector. Hence, Malaysia as one of the leading CPO producers in the world is well positioned for the biogas development with vast amount of POME generated during the milling process of CPO.

Fig. 3 reflects the growing trend of palm oil industry in Malaysia. Due to higher demand in palm oil products, the oil palm plantation has expanded vastly in Malaysia (especially in Sabah and Sarawak) for the past 10 years from 3.67 million hectares in 2002 to 5 million hectares in 2011. This expansion has eventually led to an output of 58.8% increase in the amount of CPO production from year 2002 to 2011 where there were 18.91 million tonnes of CPO produced in 2011 (Fig. 3). Based on the average of 3 tonnes of POME generated per tonne of CPO produced, the amount of POME generated in palm oil mills has increased 1.6 times from 2002 to 2011 as illustrated in Fig. 4. It is estimated that about 57 million tonnes of POME was generated in 2011 alone (Fig. 4).

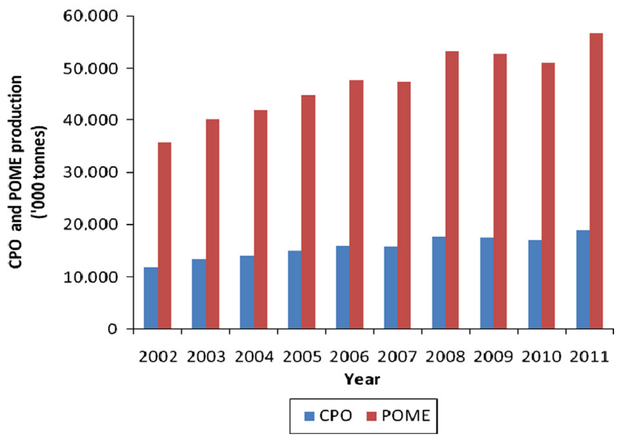


**Fig. 4.** Estimated POME generation based on the CPO production in Malaysia [60,61].

**Table 2**
Estimated biomethane production from POME based on the CPO production of Malaysia in 2011.

| Parameter | Unit | Value |
|---|---|---|
| CPO production | Tonnes | 18,911,520 |
| POME generated[a] | $m^3$ | 56,734,560 |
| COD level in POME[b] | mg/L | 51,000 |
| COD converted[c] | Tonnes | 2,314,770 |
| **$CH_4$ produced**[d] | Tonnes | **578,693** |
| Energy rate[e]: | MJ | 28,934,625,600 |
| | MWh | 8,037,396 |
| **Diesel equivalent**[f] | L | **823,316,230** |
| **Electricity generated**[g] | MWh | **3,214,958** |
| **Power plant capacity (gas engine)**[g] | MW | **401.87** |

[a] Assume that 3 $m^3$ POME generated per tonne CPO produced.
[b] COD of POME based on mean value given by Malaysia Palm Oil Board (MPOB) [11].
[c] Assume that digester efficiency is 80%.
[d] Theoretical methane conversion factor is 0.25 kg $CH_4$ per kg COD [66].
[e] Calorific value of $CH_4$ is 50 MJ/kg.
[f] Calorific value of diesel is 35.144 MJ/L.
[g] Assume the gas engine operating 8000 hr/yr and with efficiency of 40%.

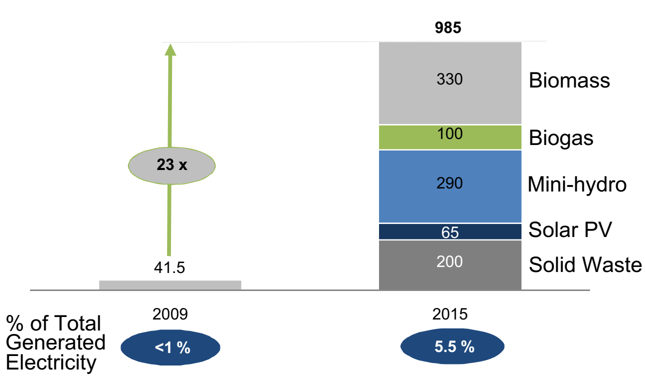


**Fig. 5.** Planned increase in renewable energy capacity (MW) in Malaysia [21].

Hence, if all these POME are treated anaerobically, it is expected that more than 500k tonnes of methane could be produced (Table 2). This amount of methane gas generated is equivalent to about 800 million liters of diesel in terms of calorific value and the estimated potential energy generated from the methane is 3.2 million MWh of electricity, equivalent to 400 MW of the potential power based on a gas engine power plant with 40% efficiency.

Mahlia and Chan [20] reported that a typical household in Malaysia consumed an average of 4387 kWh electricity per year. Hence, the estimated amount of power generated using POME derived biogas is expected to be able to support about 700,000 households in Malaysia in 2011. In addition, these POME-biogas power plants can potentially facilitate Malaysia to achieve the target of Tenth Malaysian Plan (2011–2015) to install 985 MW or 5.5% share of renewable energy in the national energy mix by 2015 as shown in Fig. 5 [21].

## 3. Benefits of the biogas recovery to palm oil mills

### *3.1. Wastewater treatment*

In anaerobic digestion, complex organic matter in POME is being degraded to form methane gas. This implies that the COD and BOD level in POME are also reduced simultaneously with biogas production from POME via anaerobic digestion. Previous studies on anaerobic treatment of POME reported that the COD removal efficiency achieved was about 97.8% for anaerobic pond [18], 80% for continuous stir reactor (CSTR) [22], 80.7% for open anaerobic digester [23], 94% for anerobic filtration (AF) [24], 78% for fluidized bed [7], 98.4% for upflow anaerobic sludge blanket (UASB) [25], and 97% for upflow anaerobic sludge fixed film (UASFF) [26]. Normally the COD and BOD values of the treated effluent are still not low enough to comply with the regulation limit set by DOE. However, the industry could look into the reuse of these waters for other application such as composting [27] and cleaning process of empty fruit bunch (EFB) in extracting long fiber from EFB; this will eventually help to save the operating costs of a palm oil mill. On the other hand, to be discharged into the watercourse, these effluents could be further polished in aerobic digesters to reduce the COD and BOD level. Anaerobic treatment is often a favorable biological treatment method for high organic load wastewater like POME and is advisable to be combined with subsequent aerobic treatment to reduce the residual organic matter of the anaerobically treated POME [28].

### *3.2. Displacement of biomass and diesel as boiler fuel*

There are various ways to utilize the biogas recovered from POME to bring surplus profits to the palm oil mills. First of all, the biogas recovered could be used by the palm oil mills in package boilers or high-pressure boilers as a replacement for diesel. In a typical palm oil mill with capacity of processing 60 tonnes/hr FFB, the total methane gas derived from POME in a year is approximately 2.4 tonnes. In comparison to the calorific value of diesel, the methane gas derived from POME is equivalent to about 3.4 million liters of diesel (Table 3).

The biogas generated could also be used in biomass boilers as co-combustion fuel to reduce the usage of other biomass fuel such as palm kernel shell (PKS) and mesocarp fiber. These unutilized biomasses could be sold to other renewable industries as boiler fuel. PKS is a good quality biomass fuel as its moisture content (17%) is lower compared to other palm oil residues such as EFB (57.2–65%) [29,30]. Moreover, the heating values of PKS (16.14 MJ/kg) and mesocarp fiber (13.33 MJ/kg) [30] are high due to the residues of palm oil content. Therefore, PKS has a high economic value with market price of RM 160–RM 200/tonne [31]. In the milling process of FFB, it is about 6–7% of the FFB is left as PKS [32]. This implies that about 23,400 tonnes of PKS are generated per year in a mill with capacity of 360,000 tonnes FFB/year. If half of the PKS is sold to other industries, palm oil mills with similar capacity could generate an extra income of about RM 2 million per annum. Hence, the reduced reliance on diesel and biomass as boiler fuel could provide additional revenue to palm oil mills [22].

**Table 3**
Simulation of electricity generated from biogas captured via anaerobic digestion of POME in a palm oil mill.

| Parameter | Unit | Value |
|---|---|---|
| FFB processed per hour[a] | t/h | 60 |
| Operating hours per day[a] | h | 20 |
| Operating days per years[a] | d | 300 |
| **FFB processed per year** | t/yr | **360,000** |
| POME generated per tonne FFB processed[b] | $m^3$ | 0.65 |
| **POME generated per year**[b] | $m^3$/yr | **234,000** |
| COD in POME[c] | mg/L | 51,000 |
| COD converted[d] | t/yr | 9547 |
| **$CH_4$ produced**[e] | t/yr | **2387** |
| Energy rate[f] | MJ/yr | 119,340,000 |
| | MWh/yr | 33,150 |
| **Diesel equivalent**[g] | L/yr | **3,395,743** |
| **Power plant capacity (gas engine)**[h] | MW | **1.66** |
| Electricity generated per year[h] | kWh/yr | 13,260,000 |
| FiT rate per kWh[i] | RM | 0.34 |
| FiT duration[i] | yr | 16 |
| **Electricity sales per year**[j] | RM/yr | **4,508,400** |
| **Electricity sales in 16 years**[j] | RM | **72,134,400** |
| CAPEX (RM10 million per MW)[k] | RM | 16,575,000 |
| OPEX per year (@4% of CAPEX)[l] | RM/yr | 663,000 |
| **Net profit per year (RE sales—OPEX)** | RM/yr | **3,845,400** |
| **Payback period** | yr | **4.3** |
| **Net profit in 16 years** | RM | **44,951,400** |

[a] Based on assumption of an operating palm oil mill.
[b] Assume that 0.65 $m^3$ POME generated per tonne FFB processed [67].
[c] COD of POME based on mean value given by Malaysia Palm Oil Board (MPOB) [11].
[d] Digester efficiency is 80%.
[e] Theoretical methane conversion factor is 0.25 kg $CH_4$ per kg COD [66].
[f] Calorific value of $CH_4$ is 50 MJ/kg.
[g] Calorific value of diesel is 35.144 MJ/L.
[h] Assume the gas engine operates 8000 hr/yr and with an efficiency of 40%.
[i] Feed-in-Tariff(FiT) rate and duration set for renewable energy (RE) generated from biogas in 2012 [36].
[j] Profit earned from FiT payment by connecting to grid.
[k] Capital expenditure (CAPEX) of the biogas plant is estimated based on the rate of RM10 million per MW.
[l] Operational expenditure (OPEX) of the biogas plant is estimated at 4% of CAPEX.

### 3.3. National grid connection

Biogas generated from POME treatment can also be upgraded through scrubbing of $H_2S$ and $CO_2$ to be subsequently used in gas engine for power generation [33]. $H_2S$ and $CO_2$ have to be removed as they can potentially corrode and damage the engine parts of power generation plant through the formation of carbonic acid when $CO_2$ reacts with water and sulfuric acid when $H_2S$ reacts with water. In line with the target of achieving 5.5% of national grid-connected electricity generation from renewable sources by 2015, the palm oil mills could gain additional profit through the utilization of biogas produced from anaerobic POME treatment for power generation by connecting the electricity generated to the national electricity grid. As to date, four oil palm biogas projects were approved to be Feed-in Approval Holders (FIAHs) for grid connection under feed-in-tariff (FiT) system, with two biogas plants already connected to the grid with a total capacity of 3.25 MW. The two biogas plants are Bell Eco Power SDN. BHD. located at Batu Pahat, Johor and Achi Jaya Plantations SDN. BHD. located at Chaah, Johor with the capacity of 2 MW and 1.25 MW respectively [34]. Bell Eco Power SDN. BHD. has generated 1436 MWh of electricity in year 2010 and sold 1195 MWh to Tenaga Nasional Berhad (TNB) which is the main electricity Distribution Licensee (DL) in Peninsular Malaysia [35].

As in 2012, FiT system in Malaysia has set the FiT rate for biogas plant with installed capacity of up to 4 MW at a basic rate of RM 0.32 per kWh. Additional bonus FiT rates of RM 0.02 per kWh will be applied to plants that use gas engine with electrical efficiency of above 40% and RM 0.01 per kWh for plants that use locally manufactured or assembled gas engine technology. The FiT duration for biogas resources is 16 years which means that the renewable electricity could be sold to distribution licensees (e.g Tenaga Nasional Berhad) and paid with the FiT during this period of time [36].

Table 3 shows the estimated profit that can be earned from the electricity generation from biogas using POME as source in a typical palm oil mill (60 tonnes/hr FFB). By setting up a biogas plant with gas engine of 40% efficiency, the power plant capacity installed is about 1.66 MW and the palm oil mill will potentially earn a net profit of up to RM 3.8 million per year through producing grid electricity (FiT of RM 0.34 per kWh). By taking the capital expenditure (CAPEX) of biogas-powered plant to be RM 16.6 million (RM 10 million/MW), the payback period for this investment will take approximately 4.3 years and the total net profit in 16 years from FiT payment is estimated to be up to RM 45 million. Hence, with the implementation of FiT system, the palm oil mills can be more convinced on the viability of the biogas plant to bring profit to the mills.

### 3.4. Clean development mechanism (CDM)

The utilization of the methane gas recovered from anaerobic digestion of POME for power generation also allow the palm oil millers to earn extra revenue by participating in the clean development mechanism (CDM) program under Kyoto protocol [37]. Besides reducing the emission of greenhouse gas to the atmosphere, palm oil millers could also trade the certified emission reductions (CERs) or carbon credit obtained from the renewable energy project to the developed countries. The profits from the CERs sales could be then used to support the operating cost of the biogas plant. The implementation of CDM in Malaysia has encouraged the development of anaerobic treatment for POME.

As of September 2012, there were 36 biogas recovery projects from the oil palm industry in Malaysia that registered with the CDM program as shown in Table 4. Out of these projects, the estimated CERs that can be generated from each project ranged from 14,848 to 78,962 tonnes per year. Hence, based on the carbon credit price in 2011 of RM 43/$CO_2$e (per tonne $CO_2$ equivalent) [38], each mill can potentially earn an additional revenue of RM 600,000 to RM 3 million per annum.

### 3.5. Financial assistance for renewable energy

As an effort to promote the development of green technology activities, the Malaysia government has established the Green Technology Financing Scheme (GTFS) which will benefit companies of green technology producers and users. The maximum financing amount offered to green technology producer and user are RM 50 million (tenure up to 15 years) and RM 10 million (tenure up to years) per company respectively [39]. Biogas recovery project in palm oil mill is one of the green projects that are eligible to apply this financial scheme.

As incentives to green projects, the Malaysia government will bear 2% of the total interest rate of the loan approved and also provide a guarantee of 60% on the financing amount, with the remaining 40% of the financing risk to be borne by participating financial institutions. Moreover, it was announced recently in the Budget 2013, the fund for GTFS will be increased by RM 2 billion from the previous allocation of RM 1.5 billion (Budget 2010) and the application period will be extended for another three years, ending 31 December 2015 [40]. Hence, this financial assistance will eventually help to facilitate the installation of biogas plants in the palm oil mills in Malaysia.

**Table 4**
CDM registered biogas projects from Malaysia palm oil industry [68].

| Registered date | Title | Project reference | Estimated $CO_2$e reduction (tonnes/year) |
|---|---|---|---|
| 8-Apr-07 | Kim Loong methane recovery for onsite utilization project at Kota Tinggi, Johor, Malaysia. | 867 | 57,656 |
| 8-Nov-07 | Methane recovery and utilization project at United Plantations Berhad, Jendarata Palm Oil Mill, Malaysia | 1153 | 20,271 |
| 19-Mar-08 | Methane recovery and utilization project at TSH Kunak Oil Palm Mill | 916 | 76,610 |
| 17-Jun-08 | Methane recovery in wastewater treatment, Project AMA07-W-01, Perak, Malaysia | 1616 | 57,094 |
| 27-Sep-08 | KKSL Lekir biogas project, Project BCM07_SLK_14 | 1888 | 33,955 |
| 22-Oct-08 | Methane recovery for onsite utilization project at Desa Kim Loong Palm Oil Mill, Sook, Keningau, Sabah, Malaysia | 1737 | 38,340 |
| 26-Jan-09 | Methane capture and on-site power generation project at Sungai Kerang Palm Oil Mill in Sitiawan, Perak, Malaysia | 2185 | 78,962 |
| 26-Jan-09 | Methane capture and on-site power generation project at Syarikat Cahaya Muda Perak (Oil Mill) Sdn. Bhd. in Tapah, Perak, Malaysia | 2181 | 67,133 |
| 14-Feb-09 | Methane recovery and utilization through organic wastewater treatment in Malaysia | 2313 | 43,152 |
| 15-Mar-09 | FELDA Serting Hilir biogas power plant project | 2336 | 37,251 |
| 19-Mar-09 | Methane recovery and utilization project at TSH Sabahan Palm Oil Mill, Sabah, Malaysia | 2332 | 53,439 |
| 20-Mar-09 | Methane recovery and utilization project at TSH Lahad Datu Palm Oil Mill, Sabah, Malaysia | 2330 | 33,356 |
| 18-Jul-09 | FELDA Besout POME biogas project | 2542 | 22,764 |
| 4-Sep-09 | Felda Pancing and Pasoh biogas project | 2603 | 34,290 |
| 19-Sep-09 | Felda Chalok and Jerangau Barat biogas project | 2651 | 32,666 |
| 15-Oct-09 | Felda Maokil and Kemahang POME biogas project | 2653 | 42,759 |
| 12-Nov-09 | AMA08-W-22, methane recovery in wastewater treatment, Johor, Malaysia | 2641 | 17,646 |
| 12-Nov-09 | AMA08-W-21, methane recovery in wastewater treatment, Johor, Malaysia | 2632 | 21,671 |
| 12-Nov-09 | AMA08-W-24, methane recovery in wastewater treatment, Pahang, Malaysia | 2642 | 26,568 |
| 12-Nov-09 | AMA08-W-25, methane recovery in wastewater treatment, Pahang, Malaysia | 2602 | 35,472 |
| 13-Nov-09 | MY08-WWP-26, methane recovery in Wastewater Treatment, Pahang, Malaysia | 2657 | 30,692 |
| 13-Nov-09 | Methane recovery in wastewater treatment, Project AMA07-W-05, Pahang, Malaysia | 2655 | 35,174 |
| 13-Nov-09 | AMA08-W-23, methane recovery in wastewater treatment, Sarawak, Malaysia | 2635 | 20,002 |
| 13-Nov-09 | AMA08-W-08, methane recovery in wastewater treatment, Sabah, Malaysia | 2656 | 19,634 |
| 13-Nov-09 | Methane Recovery in Wastewater Treatment, Project AMA07-W-07, Kedah, Malaysia | 2665 | 44,248 |
| 16-Nov-09 | MY08-WWP-36, methane recovery in wastewater treatment, Pahang, Malaysia | 1738 | 22,092 |
| 25-Nov-09 | MY08-WWP-34, methane recovery in wastewater treatment, Pahang and Negeri Sembilan, Malaysia | 1756 | 30,472 |
| 21-Dec-09 | AMA08-W-10, methane recovery in wastewater treatment, Kedah, Malaysia | 2623 | 45,392 |
| 8-Oct-10 | Sungei Kahang POME biogas recovery for energy project in Johor, Malaysia. | 3686 | 65,883 |
| 29-Dec-10 | KDC MILL 1 AND MILL 2 BIOGAS PROJECT | 3639 | 39,806 |
| 25-Jan-11 | Biogas recovery at Ulu Kanchong palm oil mill | 3125 | 33,503 |
| 26-Jan-11 | Biogas plant at United Plantations Berhad, UIE palm oil mill | 3622 | 14,848 |
| 5-Mar-11 | MY08-WWP-30, methane recovery in wastewater treatment, Pahang, Malaysia | 4216 | 26,983 |
| 31-Aug-11 | Biogas project at prolific yield palm oil mill | 4285 | 38,883 |
| 14-Sep-11 | Biogas plant at United Plantations Berhad, ULU BASIR palm oil mill | 5150 | 23,973 |

## 4. Methane gas production from POME in Malaysia palm oil biogas plants

As mentioned in Section 1, ponding system is the most conventional method for POME treatment by the palm oil mills in Malaysia. Therefore, the easiest way to implement biogas plant in palm oil mills is by covering the existing open anaerobic ponds with synthetic high-density polyethylene (HDPE) geo-membrane or linear low density polyethylene (LLDPE) to capture the biogas released [41,42]. Currently, there are several companies in Malaysia that provide technologies for biogas plants implementation in palm oil mills such as Novaviro Technology Sdn Bhd, Biotec International Asia Sdn Bhd, Biogas Environmental Engineering Sdn. Bhd., etc. Table 5 shows the methane gas production that were monitored from a number of the biogas plants installed in the Malaysia palm oil mills. Based on Table 5, most of the palm oil mills in Malaysia installed sealed cover over existing anaerobic POME ponds to create an anaerobic digester system as it is more economical and easier to operate compared to other anaerobic digester technologies. However, there are still a number of mills in Malaysia invested on the closed anaerobic digester tanks as this system provides higher methane gas production [43–47].

In addition, it was also observed that in average, the closed anaerobic digester tanks have better performance compared to the covered anaerobic ponds in terms of the amount of methane gas produced per kg of COD treated in the system. The closed anaerobic digester tank was capable of generating up to 0.23 (0.07–0.23) kg of methane gas per kg COD treated while the highest methane production of covered anaerobic pond was only 0.16 (0.03–0.16) kg of methane gas per kg COD treated. This observation is due to the lower efficiency of anaerobic pond system which lacked of operational control and has long retention time for degradation [16,17]. Nevertheless, a different trend was observed for Sungei Kahang Palm Oil Sdn. Bhd and Bell Palm Industries Sdn. Bhd. biogas plants where their methane production (0.10 and 0.07 kg of methane gas per kg COD treated respectively) were much lower compared to the other biogas plants which implemented closed anaerobic digester tanks. These unexpected monitoring results were probably due to the high organic matter content in POME treated in Sungei Kahang Palm Oil Sdn. Bhd and Bell Palm Industries Sdn. Bhd. biogas plants (140.98 kg COD/$m^3$ and 105.97 kg COD/$m^3$ respectively) which overloaded the systems; hence reducing the efficiency of the anaerobic digester tanks.

Since the methane produced from covered anaerobic ponds were relatively low, methane generated from these ponds were not utilized in the plant for energy generation but instead flared to the atmosphere. Although flaring the biogas could reduce the GHGs effect as methane has higher global warming potential than carbon dioxide, but it is a waste of bioenergy if the biogas captured is not being utilized. Hence, the government and palm oil mills should work together to upgrade the anaerobic digestion technology being used in POME treatment in order to harvest this valuable methane gas which will facilitate the boosting of national renewable energy industry.

**Table 5**
Methane gas production from POME in Malaysia palm oil mills.

| Biogas plant | Monitoring Duration (days) | Volume of POMEtreated ($m^3$) | COD in POME ($kg/m^3$) | $COD_{in}$ (kg) | $CH_4$ production (tonnes) | CH4 produced/ $COD_{in}$ (kg/kg) | Technology | Utilization | References |
|---|---|---|---|---|---|---|---|---|---|
| Sungai Kerang Palm Oil Mill, Sitiawan, Perak, Malaysia | 273 | 211,475 | 52.09 | 11,015,733 | 2497 | 0.23 | Closed anaerobic digester tank | Boiler and flare system | [44] |
| Syarikat Cahaya Muda Perak (Oil Mill) Sdn. Bhd. in Tapah, Perak, Malaysia | 275 | 232,745 | 56.69 | 13,194,314 | 2890 | 0.22 | Closed anaerobic digester tank | Boilers, gas engine and flare system | [43] |
| United Plantations Berhad, Jendarata Palm Oil Mill, Malaysia | 700 | 226,641 | 72.09 | 16,338,519 | 3239 | 0.20 | Closed anaerobic digester tank | Boiler and flare system | [45] |
| Ulu Kanchong Palm Oil Mill, Negeri Sembilan | 463 | 226,204 | 86.03 | 19,460,330 | 3172 | 0.16 | Covered pond | Boiler and flare system | [69] |
| Kilang Kelapa Sawit Jengka 8, Pahang | 244 | 93,328 | 57.80 | 5,394,358 | 829 | 0.15 | Covered pond | Flare system | [70] |
| Kim Loong Palm Oil Mill, Kota Tinggi, Johor, Malaysia. | 699 | 491,783 | 63.77 | 31,361,002 | 4503 | 0.14 | Closed anaerobic digester tank | Boiler and flare system | [46] |
| Kilang Kelapa Sawit Serting, Negeri Sembilan | 244 | 119,887 | 33.70 | 4,040,192 | 528 | 0.13 | Covered pond | Flare system | [70] |
| Kilang Kelapa Sawit Arah Kawasan Sdn Bhd, Kedah | 366 | 315,873 | 59.49 | 18,791,285 | 2245 | 0.12 | Covered pond | Flare system | [71] |
| Endau Palm Oil Mill Sdn Bhd | 212 | 246,359 | 76.04 | 18,732,399 | 1973 | 0.11 | Covered pond | Flare system | [72] |
| Sungei Kahang Palm Oil Sdn. Bhd, Johor, Malaysia. | 550 | 362,915 | 140.98 | 51,162,144 | 5235 | 0.10 | Closed anaerobic digester tank | Boiler and flare system | [47] |
| Bukit Bujang Palm Oil Mill in Segamat, Johor | 425 | 173,070 | 61.60 | 10,661,112 | 1074 | 0.10 | Covered pond | Flare system | [73] |
| PPNJ Kahang Palm Oil Mill, Johor, Malaysia | 415 | 241,139 | 67.80 | 16,349,225 | 1378 | 0.08 | Covered pond | Flare system | [74] |
| KKS RH Plantation in Miri, Sarawak | 336 | 451,698 | 32.23 | 14,558,678 | 1196 | 0.08 | Covered pond | Flare system | [75] |
| Bell Palm Industries Sdn. Bhd. | 184 | 70,425 | 105.97 | 7,463,219 | 529 | 0.07 | Closed anaerobic digester tank | Gas engine and flare system | [76] |
| Foong Lee Sawiminyak Sdn Bhd, Perak | 336 | 332,526 | 56.80 | 18,887,461 | 1199 | 0.06 | Covered pond | Flare system | [77] |
| SetiaKawan Kilang Kelapa Sawit Sdn Bhd | 396 | 272,694 | 52.90 | 14,425,516 | 913 | 0.06 | Covered pond | Flare system | [78] |
| Rompin Palm Oil Mill Sdn Bhd in Pahang | 306 | 445,683 | 58.40 | 26,027,887 | 1083 | 0.04 | Covered pond | RE unit and flare system | [79] |
| Keningau Palm Oil Mill, Sabah | 365 | 564,168 | 49.19 | 27,751,424 | 1008 | 0.04 | Covered pond | Flare system | [80] |
| Wujud Wawasan Sdn Bhd, Pahang | 291 | 793,781 | 47.20 | 37,466,463 | 1115 | 0.03 | Covered pond | Flare system | [81] |
| Kilang Kosfarm Sdn Bhd, Pahang | 641 | 626,459 | 60.50 | 37,900,770 | 1012 | 0.03 | Covered pond | Gas engine and flare system | [82] |

## 5. Current challenges

Malaysia government is looking into the development of biogas plant utilizing POME in order to boost up the renewable energy sector as well as to reduce the carbon foot print in the country. One of the effort implemented by the government is Entry Point Project No 5 (EPP 5) under the National Key Economic Areas (NKEA) which aims to achieve the installation of biogas facilities in all palm oil mills in Malaysia by 2020 [48]. As shown in Fig. 6, there are 426 palm oil mills throughout Malaysia in 2011. However, out of these, there are only 55 mills (12.9%) that have completed biogas plants installed in their mills while 16 (3.8%) under construction and another 150 (35.2%) under planning [49]. This shows that there are still about 50% of the palm oil mills in Malaysia still opting the conventional ponding system and open tank digester system as POME treatment where uncollected methane gas is dissipated into atmosphere. Hence, the growth of biogas installation in palm oil mills is relatively slow to achieve the aim of EPP 5 in year 2020. The opportunities of biogas captured from POME are well known and accepted by the millers but there are a number of barriers that have hindered its development.

One of the key barriers is the relatively high investment cost to build biogas plant with power generation system in the palm oil mills as compared to the conventional ponding treatment system.

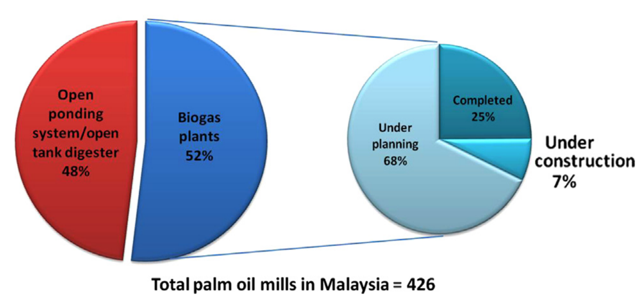


**Fig. 6.** Development of biogas plants in palm oil mills in Malaysia 2012 [11,49].

Utilization of POME-derived biogas as renewable energy is considered as new technology and hence financing these projects is perceived as high risk investment. Moreover, the palm oil millers have the belief that this investment will not be viable economically as it does not give immediate profit return and requires a long payback period (about 5 years via FiT payment). In addition, there is lack of successful models in POME-biogas plant to persuade the palm oil mill operators to install biogas plants in their mills.

Furthermore, most of the palm oil mills are not capturing and utilizing the methane gas from POME as there is no enforcement to do so. As in Malaysia, there were no regulations or restrictions

on the release of biogas into the atmosphere. Since there is also no standard technology for POME management, it is obvious that without incentives, the most likely scenario for POME treatment at the palm oil mills is via ponding system as the operational cost is low and these mills do not face problems with restricted land space for POME treatment; thus resulting in uncontrollable emission of greenhouse gases (GHGs) to the atmosphere.

In addition, anaerobic digestion of POME to generate biogas is considered as a complex process. The seasonal nature of palm oil milling operation has caused the characteristics of POME to vary throughout the year [8], causing operational uncertainties to the biogas plant. This is due to the low tolerance of anaerobic digesters to shock loading. During the high crop season, the high loading rate may cause system failure to the biogas plant and cease methane production. The instability of the biogas production will subsequently decrease the efficiency of the system and influence the sustainability supply of the renewable energy. Therefore, this system requires dedicated and skilled manpower for operation, which eventually increases the operational cost of the system. Lack of local expertise on the handling of biogas plant utilizing POME is also a constraint to ensure stability of the system for continuous methane production and this eventually reduces the confidence level of the palm oil mills on the viability of the biogas plant.

Aforementioned, there were 55 oil palm biogas plants installed in Malaysia but only four biogas plants were approved for the FiT system with two plants connected to the grid. For other biogas plants, the electricity generated are used in-house for the mill operation. One of the reasons which limits the national grid connection of this biogas plants is that the FiT system is only applicable to Sabah and Peninsular Malaysia under the Renewable Energy Act 2011 [50]. According to this act, FiT is not applicable in Sarawak as it has its own legislation and regulations governing the electricity supply and hence exempted from the renewable energy (RE) levy. Moreover in Sabah, the implementation of FiT system was delayed due to the absence of adequate FiT fund for Sabah. The 1% FiT levy on the state's electricity tariff was postponed since December 2011 [51]. As such, this implies that the FiT is currently only made available to peninsular Malaysia while RE producers in Sabah and Sarawak, mostly biomass and biogas plant operators at palm oil mills, will not enjoy the RM 0.32/kWh under the FiT; subsequently decreasing the interest of palm oil mills to invest on a biogas plant. Palm oil mills in Malaysia already has enough electricity generated from the steam boiler and steam turbines by burning its own fiber and shell, hence the electricity generated from the biogas plant is less attractive to the mills without the FiT system [15].

On top of that, for national grid connection, the distance between the biogas power generation plant and the location of the interconnection point at the distribution system must be within 10 km to avoid power lost. However, most of the palm oil mills especially those in Sabah and Sarawak is located in rural areas which located far from the interconnection point. Therefore, it is difficult for these power plants to be connected to national grid as longer connection distance will increase the connection cost and also power lost.

In a regulated electricity market such as in Malaysia, the funding source for FiT is limited to a fixed percentage imposed on the utility's electricity revenue (1% FiT levy on electricity tariff). Therefore, there are caps on the RE installed capacities to ensure that there will be adequate funds to make the FiT payments to RE generators. However, these RE quota will in turn limit the RE growth in Malaysia and constrain the grid connection of RE from POME-derived biogas plant as well.

In addition, the CDM program under Kyoto Protocol is due to expire at the end of 2012 where CDM projects that are approved after December 31, 2012 are barred from exporting CERs to Europe's Emissions Trading Scheme. This implies that there will be no financial support through the sales of CERs to assist the development of new biogas plants in palm oil mills. Only those CDM projects that have been accepted before end of 2012 will be prolonged to mid-2015 [52]. Moreover, the CERs price has declined from €10 in 2007 [53] to around €2 in 2012 [51,54] due to an oversupply of carbon credits, generated by the CDM. It was predicted that the CER price will decline from €2 to 50 cents by 2020 [51]. Hence the low price of CER may discourage the investment in biogas plants over the coming years.

## 6. Future direction of POME-biogas power generation plant

The development of biogas plants in palm oil mills across the country will be a reliable step to boost the RE industry in Malaysia as palm oil industry is the fourth largest contributor to the national income in Malaysia [38] and its growth is in an escalating trend. Hence, POME will be a sustainable source for the biogas plant to generate RE and subsequently increase the RE share in the energy generation mix in Malaysia.

Nevertheless, in order to install biogas plant in all palm oil mills and also to achieve 11% share of renewable energy in the energy mix in Malaysia by 2020 [55], immediate action plans have to be carried out to lower the hurdle of the development of biogas plant in palm oil mills. Government should strengthen and formulate the regulatory framework of capturing methane gas from anaerobic digestion of POME. This will eventually promote the shift from the open ponding system to biogas plant for methane gas capture. In addition, government should provide special incentives and tax reduction to RE producers especially to the palm oil mills to assist them with the high capital investment of the biogas power generation plant.

On the other hand, the FiT system should be implemented as soon as possible in Sabah and Sarawak. Government subsidy will be necessary in Sabah due to lack of RE funding. Besides, higher FiT quota should be allocated for RE implementation in Sabah since there is more urgent need on the power generation plant compared to peninsular Malaysia. For grid connection, those palm oil mills that located near to each other but far away from the national grid interconnection point could connect their biogas plant together to form a mini-grid system for rural application. This system could be applicable to Sabah and Sarawak areas where national grid electricity is difficult to be supplied to rural areas.

Currently, the application of anaerobic digestion of POME in Malaysia is mostly conducted using single-phase system where all the biochemical reactions involved in anaerobic digestion take place in a same reactor [56]. However, the low tolerance to loading shock and instability of single-phase anaerobic reactor during high loading rate has caused the POME treatment inefficient as POME characteristics vary throughout the year. Therefore, two-phase anaerobic digestion (TPAD) could be used as a solution to these issues. Two-phase anaerobic treatment has been successfully implemented for many types of wastewaters and was found to have greater stability and higher methane production rate compared to one-phase anaerobic digestion [56,57]. However, wastewater characteristics highly affect the performance of the TPAD because the optimum operating parameters vary with the characteristics of substrates being treated. Thus, an in-depth investigation should be carried out for the TPAD of POME to fully optimize each reactor as TPAD can potentially boost up the methane production from POME while providing greater system stability. Researches should be focused to optimize the methane yield from anaerobic digestion of POME to increase the calorific value of biogas produced alongside with the COD removal. Higher methane generated translates to greater revenues to the palm oil mills and

this move will be aligned to the worldwide growing perspective of green technology.

## 7. Conclusion

Bioenergy from treatment waste is an economical alternative to fossil fuels, therefore potentially growing to be the most significant renewable energy source in the next few decades. All these while, POME treatment in Malaysia was mainly conducted to comply with government regulations. However, the potential of using POME as a source for biogas generation that can be used as renewable energy has been neglected. POME has high content of COD in the form of carbohydrates, proteins and lipids and it is produced in large amount in all palm oil mills in Malaysia. Hence, POME is well-positioned as a great potential source for bioenergy (methane) production.

As one of the largest contributor to Malaysia's national economy, palm oil industry can be foreseen to continue its growing trend in future and POME can potentially become a sustainable source for biogas in Malaysia. Since POME is a free feedstock for biogas production and is abundant in all palm oil mills; hence it ensures continuous supply of substrates at no cost for biogas production. It is expected that more than 500k tonnes of methane could be produced in year 2011 alone if all the POME generated are being treated anaerobically and the estimated potential energy generated from the methane is 3.2 million MWh which is expected to be able to support about 700,000 households in Malaysia in 2011. Therefore, anaerobic digestion is a good treatment method for POME as it converts the waste to RE that will benefit the palm oil mills and government in terms of environment image and profit.

Nevertheless, there are barriers that hindered the development of RE utilizing POME as a renewable source. The current methane gas production from POME in Malaysia is still below expectation as most of the palm oil mills in Malaysia are still reluctant to venture into higher efficiency technologies such as closed anaerobic digester tank due to cheaper operating costs and ease of operation. Therefore, there is a need to improve on the anaerobic technology in converting the organic matter in POME to the valuable methane gas. Moreover, more financial assistances will be required and more researches should be carried out to improve the technology used in anaerobic digestion of POME to increase the methane production. With the enhancement in the anaerobic digester technology of POME, it is undeniable that POME will act as a good biogas resource to boost Malaysia's RE sector in the future.

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